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ABSTRACT

Three types of vacuum filters and their operation are described in this lesson. Typical filter cycle, filter components and their functions, process control parameters, expected performance, and safety/historical aspects are considered. Conditioning methods are also described, although it is suggested that lessons on sludge characteristics, sludge conditioning, and heat treatment be studied before undertaking the lesson. The lesson includes an instructor's guide and student workbook. The instructor's guide contains a description of the lesson, estimated presentation time, instructional materials lists, suggested sequence of presentation, reading lists, objectives, lecture outline, narrative of the slide/tape program used with the lesson, and student worksheet (with answers). The student workbook contains plant flow diagrams, objectives, glossary, vacuum filter text material, references, and worksheet. (JN)

# SLUDGE TREATMENT

and

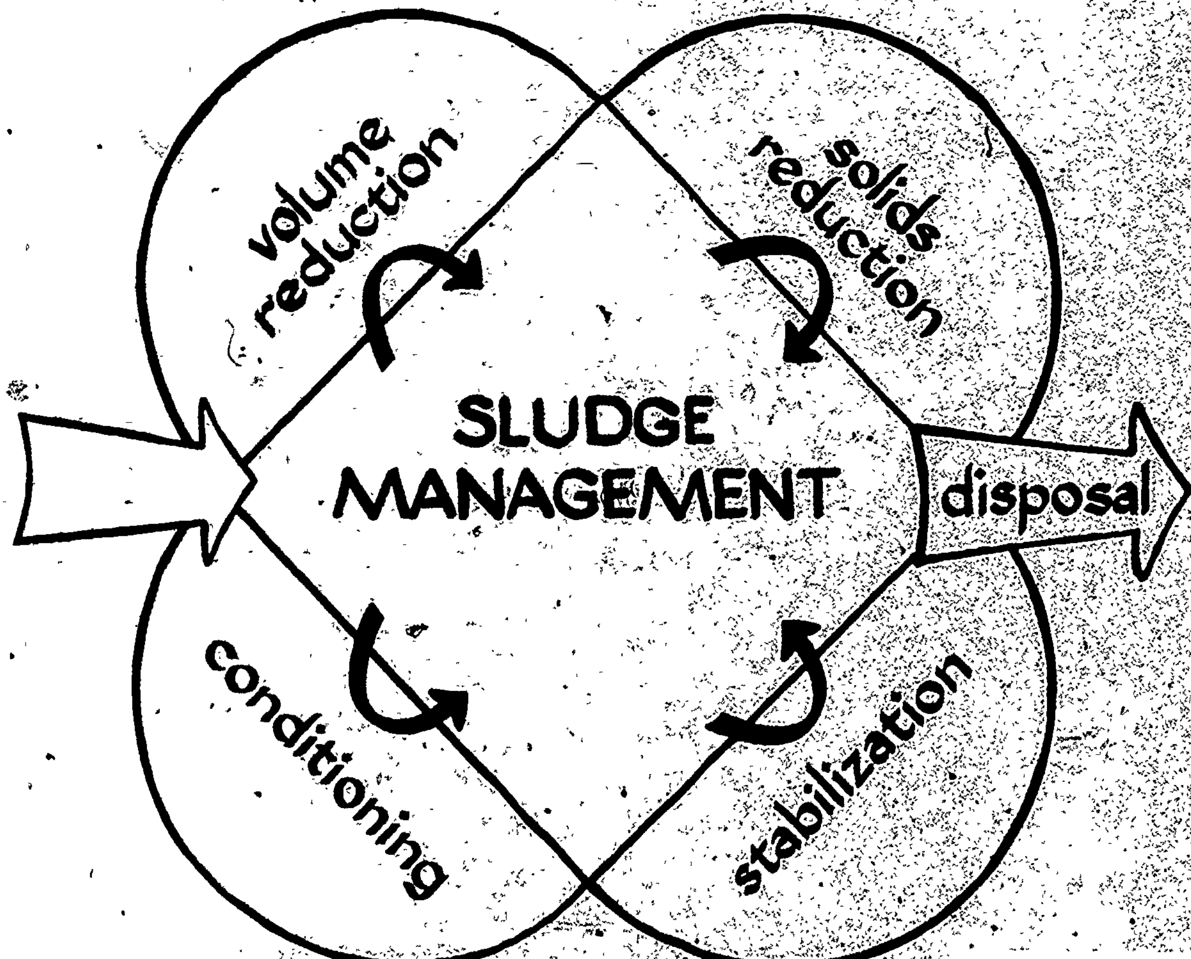
# DISPOSAL

## COURSE # 166

## VACUUM FILTRATION










## INSTRUCTOR'S GUIDE



Prepared by
Linn-Benton Community College
and
Envirotech Operating Services

# VACUUM FILTRATION

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VACUUM FILTRATION

CONTENTS

# VACUUM FILTRATION

## Lesson Description

This lesson describes the operation of the vacuum filter. It begins with a basic definition of the process, then discusses history and the three types of vacuum filters. Conditioning methods are described, although it is suggested that the lessons on sludge characteristics, sludge conditioning and heat treatment be studied before undertaking this lesson. This module describes a typical filter cycle, components and their function, process control parameters, expected performance and safety.

## Estimated Time

| | |
|---|---|
| Student preview of glossary and objectives | 5-10 minutes |
| Presentation of lesson | 45-60 minutes |
| Worksheet | 10-20 minutes |
| Correct worksheet and discussion | 10 minutes |

## Instructional Aids

1. Student text "Vacuum Filtration"
2. Slide set "Vacuum Filtration"
3. Slide projector
4. Screen and pointer
5. Samples of filter media
6. Chalkboard or flipchart for discussion period

## Suggested Sequence of Presentation

1. Assign reading - emphasis on glossary and objectives
2. Lecture from outline using 35 mm slide support
3. Open discussion
4. Assign worksheet
5. Correct worksheet

## Required Reading

Vacuum Filtration, EPA Course #166

## Reference Reading

Sludge Dewatering, Manual of Practice 20, WPCF, 1969.

Objectives

Upon completion of this lesson the student should be able to do the following:

1. Define filtration.
2. Describe how atmospheric pressure is used as the driving force to accomplish filtration.
3. Recall that the purpose of vacuum filtration is to remove water from the sludge so that the sludge volume and operating costs are reduced.
4. Recall the two different types of vacuum filters: 1) Drum-scraper, 2) Moveable belt.
5. Recall that the filter medium or cloth can be made from a variety of materials.
6. Recongnize the four operating zones and recall what occurs in each of them: A) forming, B) drying, C) discharge, D) washing.
7. Recall the function of the filter drum.
8. Recall that the filter vat holds a reservoir of sludge.
9. Recall that the vat agitator helps to keep the sludge suspended in the vat and prevents stratification.
10. Recall that the demooning bar supports the media from the drum to the discharge roller.
11. The edge track guide guides the cloth from the drum to the discharge roller.
12. Recall that the discharge roller is where the cake falls from the media to the conveyor.
13. Recall that the wash sprays are to keep the cloth clean.
14. Recall that the vacuum filter control valve controls the vacuum to the forming zone and drying zone.
15. Recall the filtrate receiver separates the water, solids and air.
16. Recall that the vacuum pump is the heart of the vacuum filter.
17. List some of the other equipment sometimes supplied to improve operation..
18. Describe how vacuum filter operations can be influenced by: A) Sludge type, B) sludge conditioning, C) applied vacuum, D) drum speed, E) drum submergence, F) media type.
19. Recall that for best operational results feed sludges should have 3% or more solids concentration.
20. Recall that the vacuum filter yield is expressed in pounds per hour per square foot of media (lbs/hr/ft$^2$).

21. Recognise the term "blinding" as used to describe clogged media.

22. Recall that biasing is a media condition where one side is ahead of the other.

23. Mooning is a media condition where bowing occurs and this is due to cake weight.

## VACUUM FILTRATION - LESSON OUTLINE

I. Vacuum Filtration - The Basics

A. Definition

1. Mechanical Process

a. Vacuum draws sludge from a vat against a straining media

b. Cake is formed

c. Moisture pulled from sludge

d. Cake discharged, carried to next processing area

e. Filtrate (liquid portion) returned as sidestream to wet end of plant

B. Purpose

1. Remove water from sludge

2. Volume of sludge is reduced

3. Operating costs are reduced in subsequent and solids processing steps.

II. History

A. First patent - England 1872 (William & James Hart)

B. U.S. applications

1. 1920's - First vacuum filter

2. 1920's - 1960's

a. Drum & scraper rotary vacuum filters most predominant

3. Present

a. Belt - type

(1) Natural or synthetic fiber cloth

(2) Woven stainless steel mesh

(3) Coil springs

III. Process theory & background information

A. Mechanical process by which:

1. Liquid removed from sludge

2. Volume of sludge reduced

3. Feed sludge to filter should be 4-10%

B. Types of filters

1. Drum

2. Coil

3. Belt

C. All filters are similiar except:

1. Mechanism for cake discharge varies
2. Type of filter covering (media)

D. Sludge conditioning for vacuum filters

1. Heat treatment
   a. High temperature & pressure
   b. Releases bound and intracellular water
   c. Sludge dewaters better, water extracted
      (1) Filter called "extractor"
2. Chemical conditioning
   a. Choices:
      (1) Lime
      (2) Ferric chloride
      (3) Polymers
   b. Action:
      (1) Coagulant to improve dewaterability of floc
      (2) Surface charges neutralized
      (3) Floc & capillary water released
3. Elutriation
   a. Sludge is washed to remove alkalinity and fine particles
   b. Reduces coagulent requirements
4. Conditioning improves:
   a. Production rates
   b. Solids capture
   c. Cake solids contact

IV. General vacuum filter operations

A. Filter cycle - 1 full revolution of the drum, 4 parts

1. Form cycle (cake formation)
   a. Sludge drawn to media by vacuum
   b. Cohesive cake formed
2. Drying cycle
   a. Cake emerges from vat
   b. Air being sucked through the cake and media
   c. Loses water, compresses
3. Cake release
   a. Cake mechanically removed

4. Wash
   a. Media washed
   b. Stationary and reciprocating water sprays

V. Vacuum filter components & function
   A. Vacuum filter drum
      1. Main component
      2. Tin can rotating in a vat of sludge
         a. 10-35% submerged
      3. Divided into radial sections
         a. Each piped to vacuum source
   B. Section dividers
      1. Divides drum face into sections
      2. Maintain section vacuum
      3. Holds polypropylene grids in place in each section
      4. Grids support filter cloth; applies even vacuum
   C. Vat
      1. Holds sludge (reservoir) to provide 10-35% submergence as drum rotates through it.
   D. Vat agitator
      1. Bars across the vat
      2. More back & forth for mixing
      3. Prevent stratification
      4. Caution: Too fast agitation causes floc shear
   E. Drum manifold vacuum system
      1. Piping system
      2. Inside filter drum
      3. Connects each section to vacuum control valve on side of filter
   F. Vacuum control valve
      1. Distributes vacuum to forming & drying zones
   G. Demooning bar
      1. Curved bar
      2. Between discharge roller and drum
      3. Supports cake weight (100-500 lbs.)
      4. Maintains alignment of media

H. Edge track guide
   1. Rollers which guide the media from the drum to discharge roller
I. Flapper bar
   1. optional
   2. Pipe with rubber beaters
   3. On back side of media
   4. Knock cake off
J. Discharge roller
   1. Small diameter
   2. Cake falls off onto conveyor
K. Scraper (Doctor blade)
   1. Assists discharge of cake from discharge roller
L. Wash sprays
   1. Cleans media between cycles
   2. 40-60 psi.
M. Wash roller
   1. In middle of washing action
   2. Trough underneath roller collects washings, added to filtrate, sidestream back to plant
N. Take-up roller
   1. Adjustable
   2. Maintain tension & alignment
O. Filter media
   1. Cotton
   2. Wool
   3. Satin
   4. Nylon
   5. Polypropylene
   6. Polyurethane
   7. Rayon
   8. Dacron
P. Vacuum system
   1. Filter drum manifold piping
   2. Vacuum control valve
   3. Filtrate receiver
   4. Vacuum pump

VI. Operation

A. Media adjustment

1. Mooning

a. Arched curve in the media of the fastener joint (clipper)

b. Causes wrinkling of media

(1) Loss of vacuum

(2) Poor cake formation

(3) Excessive wear

c. Caused by:

(1) Excessive cake weight

(2) Adjust demooning bar

2. Biasing

a. One end of clipper seam leads the other

b. Causes

(1) Media to creep to one side

(2) Loss of vacuum

c. Cure

(1) Take-up roller adjustment

B. Vat sludge level & drum speed

1. Vat level

a. High = more forming zone, lower drying zone

2. Drum speed

a. Controls: time of forming & drying

3. The point is:

a. Adjust vat level & drum speed to achieve equilibrium

C. Blinding

1. Filter media clogged

2. Clean it

D. Expected results

1. Production

a. 20-35% solids, chemically conditioned

b. 25-45% solids, thermally conditioned

2. Filtrate

a. Solids = 100-600 mg/l when properly operated

3. Capture
    a. 85%
4. Yield

E. Filter performance
1. Yield
    a. lbs. solids / hour / sq. ft. of drum surface area
    b. $\#/hr/ft^2$
2. Yield related to:
    a. Feed sludge conc
    b. Cake formation time
    c. Amount vacuum applied
3. Yield indirectly related to:
    a. Total cycle time - regulated by drum speed
    b. Cake solids conc
    c. Media & cake resistance

F. Operational Controls
1. Feed sludge conc - little operator control over this
2. Drum speed - Changes cycle time
3. Drum submergence - level of sludge in the vat
    a. Changes dry cycle time
    b. Changes form cycle time
4. Agitation speed
    a. Changes vat solids concentration (stratification)

G. Filter agitator
1. Prevents heavy solids in vat
2. Solids may accumulate on surface where drum emerges from vat
    a. Some dewatering occurs before solids are picked up on media
    b. Solids may get too heavy to be picked up
3. Therefore:
    a. Agitate vat
        (1) Prevent sinkers and floaters
4. Excessive agitation
    a. Floc shear
5. Agitation speed
    a. Trial & error

H. Vacuum - Vary compressant flow rate to change amount of vacuum

1. Open vacuum breaker valve

VII. Safety

A. Good housekeeping

B. Safety devices intact

C. Electrical lock-out & tag procedure

D. Chemical handling

1. Protective clothing, ventilation, breathing apparatus

2. Polymer is slippery, use salt as slip-killer

VIII. Summary

A. Mechanical process

1. Vacuum draws sludge from vat onto media

2. Draws water from sludge

3. Discharges cake

4. Volume reduction

5. Aids further solids handling processes

6. Good track record

VACUUM FILTRATION

NARRATIVE

Slide #

1. This module discusses the theory of vacuum filtration, describes the components and their functions, and outlines the factors that affect operation of the vacuum filter.

2. This module was written by Ronald M. Sharman with technical consultation by Kendall Windraw and Herb Filer. Instructional design was done by Priscilla Hardin. Paul H. Klopping was the project manager.

3. Filtration can be defined as the removal of solids from a liquid stream by passing that stream through a porous medium which retains the solids.

4. No matter what variation of the filtration process, a pressure drop or difference in pressure is required in order for liquid to flow through a porous medium.

5. Vacuum filtration, as a sludge filtration-dewatering process, uses atmospheric pressure as the driving force to accomplish filtration.

6. A decrease in pressure is formed on the inside of the filtration unit by evacuating the air with a pump. This creates a pressure drop or vacuum which allows atmospheric pressure to force the liquid through the filtration media leaving the solids behind.

7. The purpose of vacuum filtration is to remove water from wastewater sludge so that the sludge volume and operating costs are reduced for the subsequent solids handling process.

8. A vacuum filter consists of a rotating drum which continously passes through a trough or pan of sludge to be dewatered. Sludge is drawn against the filter media where the sludge is partially dried as the drum rotates.

9. The partially dried sludge or "cake" drops onto a conveyor and is moved to final disposal. The liquid portion or "filtrate" returns to the headworks of the wastewater plant for treatment.

10. There are two different types of vacuum filters. These are: the drum scraper and the movable belt filters.

11. The first filter was patented in England in 1872. It consisted of fixed media revolving through the sludge vat, and using a cake scraper or knife to remove the cake from the drum. Until the 1960's, the drum-scraper type was predominant. Since then the moveable belt type filter has predominated.

12. Moveable belt vacuum filters have a filter media which carries the sludge cake from the vat to the discharge roller where the cake is released.

13. Selection of filter media depends on sludge characteristics and manufacturers preference. Regardless of media type, whether natural or synthetic fibers, stainless steel wire mesh, or coil springs, vacuum filter operations are similar. This module will concentrate on the moveable belt type filters.

14. The filter drum is divided into four compartments or operating zones. These are the cake forming, drying, ~~discharge,~~ and wash zones. Each drum cycle contains all four operating zones. (In sequence, each compartment is subjected to different vacuum levels.)

15. The highest vacuum exists in the first compartment called "cake forming" or "sludge pick-up" zone. The forming zone starts in the vat underneath the sludge layer. Vacuum is applied to the surface of the drum within the sludge layer and the solids are drawn up against the media to form a cake.

16. As the drum rotates out of the tough, the vacuum is decreased slightly and moisture is pulled out of the cake, through the filter medium and is discharge through internal pipes to a drainage system. This is known as the "drying zone" of the cycle and it continues around to the top of the drum.

17. Just prior to the point where the medium separates from the drum, the vacuum is reduced to zero. The belt then enters the cake "discharge zone". The cake falls off the cloth at the discharge roller and onto the conveyor which carries it to the next disposal process.

18. The "wash zone" is the last zone of the operation sequence. Once the cake is discharge to the conveyor, the media must be cleaned before the next cycle. A series of water sprays, using plant effluent, cleans the media.

19. The filter drum is the main component of the vacuum filter. It is divided into radial sections. Each section is individually piped to the end of the drum where the vacuum control valve is located.

20. The drum face consists of a steel plate to which section dividers hold polypropylene grids in place at each drum section and maintain an evenly applied vacuum across the drum surface. The filter medium rides on these polypropylene grids.

21. At the "cake forming zone", there are two components that make up the sludge supply source. They are the vacuum filter vat and the vat agitator.

22. The vacuum filter vat holds sludge so that it can be drawn up onto the filter medium. It is big enough to allow approximately 10% to 35% of the filter drum to be submerged.

23. The vat agitator maintains an even sludge concentration and reduces the potential for sludge accumulation in one area of the vat. The agitator is a series of square bars which move back and forth across the bottom of the vat.

24. The vat agitator speed is adjustable so that the solids stay suspended in the vat. If the agitator speed is too slow, stratification may occur. If the agitator is too fast it will break up the floc.

25. Four basic components make up the "discharge" and "washing" zones. These are: the discharge roller, the wash sprays, the wash roller, and the take up roller.

26. The discharge roller is a small diameter roller and is the final turning point where the sludge cake falls off the medium onto the conveyor. Because of the thickness of the cake and the small diameter of the discharge roller it is difficult for the cake to make the turn and the sludge falls off.

27. Each filter normally has three wash sprays. These sprays flush the media clean preparing it to reenter the vat. The sprays operate continuously at 40 - 60 psi.

28. In the middle of this washing action is the wash roller. Below the wash roller is the trough which collects the wash water and returns it to the headworks of the plant. Because of the solids washed off the belt, the wash water must be considered as an additional load on the plant.

29. The take up roller is an adjustable roller which keeps the belt on the filter drum. Both sides of the roller are mounted on a screw with a handle. By turning the screw, the operator can adjust the take up roller to maintain belt alignment and tension on the filter drum.

30. In addition to the basic components already mentioned, other equipment may be supplied to improve operation. Some of these include: the edge track guide, the demooning bar, the flapper bar, and the doctor blade.

31. The rubber edge track of the media rides on rollers which guide the media edge from the filter drum to the dicharge roller. The purpose of the edge track guide is to help maintain belt alignment.

32. The demooning bar is a curved bar located between the filter drum and the discharge roller. During operation, filter cake moving between the drum and the discharge roller may weigh a much as 100 to 500 lbs. The demooning bar supports the media and prevents misalignment due to excess cake weight.

33. The flapper bar helps to discharge the cake from the filter belt. It consists of a pipe with a series of rubber beaters bolted onto it. The rubber beaters hit the underside of the belt and knock the cake off.

34. The doctor blade is a plastic scraper which knocks off any cake remaining on the belt after the discharge roller. The doctor blade is effective only as a cake deflector and should not come in contact with the belt.

35. The vacuum system of the filter has four essential components: the vacuum manifold piping located within the drum; the vacuum control valve which applies the two levels of vacuum to the manifold piping; the filtrate receiver, which separates the filtrate from the air flow; and the heart of the system, the vacuum pump.

36. The manifold piping carries the filtrate and evacuates air from the surface of the drum to the vacuum control valve. Each drum section has a separate vacuum pipe.

37. The different sections of the filter drum piping come together at one end of the drum and are covered by a pipe plate. This pipe plate has ports or holes corresponding to the number of filter sections pipes and rotates with the drum.

38. The bridge ring, which does not rotate with the filter drum, confines a higher vacuum to the cake forming zone and lower vacuum to the drying zone. The bridge ring seals off the manifold piping at the discharge zone. These components make up the vacuum control valve.

39. From the control valve, the filtrate enters the filtrate receiver on the side of the tank. In this tank the water, solids, and air are separated.

40. A spinning action forces the water and solids against the wall of the receiver. The filtrate is collected from the bottom and pumped to the headworks. The air portion passes out the top of the receiver on its way to the vacuum pump.

41. The vacuum pump is the heart of the vacuum filter system. Until 1960, reciprocating dry vacuum pumps were generally specified, but since the early 1970's wet type vacuum pumps are used.

42. The vacuum filter system can react quickly to process changes occurring in the treatment facility. Because it is a sophisticated mechanical process, it requires the attention of an experienced operator.

43. The following factors influence vacuum filter operations. They are: feed concentration, sludge conditioning, applied vacuum, drum speed, drum submergence, and media type.

44. The higher the suspended solids concentration of the feed sludge, the greater the production rate of the vacuum filter. In general, wastewater treatment sludges have less than 10% solids concentration. Thicker sludges are difficult to pump, mix with chemicals, and distribute.

45. Straight secondary sludges are not easily dewatered by vacuum filtration. Such sludges usually require blending with primary sludge or thermal conditioning prior to vacuum filtration. Vacuum filters work best with sludges of 3% or more solids concentration.

46. Before sludge is vacuum filtered, it is usually conditioned.

47. Conditioned sludge readily releases its water when subjected to a vacuum. The three methods of conditioning include: heat treatment, chemical conditioning, and elutration.

48. Applied vacuum controls the degree and rate of sludge pickup along with the amount of water withdrawn.

49. Low vacuum results in a wetter cake while higher vacuums produce a dryer cake. The operator should maintain as high a vacuum as possible to yield a dry, manageable cake.

50. The drum speed controls the amount of time the sludge cake is in the forming and drying zones.

51. Drum speed controls cycle time which varies from 2 to 6 minutes. The faster the drum speed, the wetter the cake. Slow drum speeds produce drier cakes.

52. The depth of drum submergence within the vat affects the formation of the sludge cake on the media.

53. As the drum submerges, more belt surface comes in contact with the sludge. Deep submergence gives greater yields while shallow submergence produces low cake yield. The depth should always be maintained within the manufacturer's recommended range.

54. Sludge characteristics influence the selection of filter media type for each specific operation.

55. Sludges with large, coarse particles are captured by media of high porosity while fine, low density solids require media of lower porosity.

56. Vacuum filter production or yield is expressed in pounds per hour per square foot of media. An average yield will give 4 to 8 lbs of solids per hour per $ft^2$, sometimes as high as 12 $lbs/hr/ft^2$. Yield is directly dependent on sludge type, conditioning, and efficiency of operation.

57. The primary goals of vacuum filter operation are: high cake yield, dry cake, good quality filtrate, and low operating costs.

58. Solids capture across a vacuum filter is usually about 85%. This means that for every 100 pounds of solids sent to the filter, 85 pounds are dewatered and removed, and 15 pounds are lost in the filtrate and sent back to the headworks of the plant. This sidestream must be considered as an additional load on the plant. A good operator will monitor filtrate concentration and watch for problems that may be created in the plant.

59. Successful vacuum filtration produces a clear filtrate and thick sludge cake. The most common problems that develop are deterioration in filtrate quality and wet cakes that are difficult to discharge from the belt. Some of the major causes are: inadequate conditioning, mooning, biasing, and blinding.

60. The operator should keep close watch on the incoming sludge type and characteristics. They can change with variations in plant loading. Careful adjustment in the conditioning process can correct this problem.

61. Mooning problems are a major cause of belt wrinkling which can result in loss of vacuum, poor cake formation, excessive wear of the cloth and damage to the rubber edging. Adjustments of the mooning bar will correct this problem.

62. Biasing occurs when the belt moves diagonally across the rollers. This may cause drum surface exposure, vacuum leaks, and eventual belt wrinkling. To correct a bias, adjust the take up roller to produce equal tension on each side of the belt.

63. Blinding occurs when sludge plugs the filter media. A clogged media usually develops when poor cake formation occurs in the "formation" zone. Whatever solids are picked up do not effectively drain in the drying zone and a wet cake develops.

64. The operator should check the condition of the media and increase the washwater rate, or turn off the sludge feed and wash the belt.

65. Good housekeeping and an orderly arrangement of material and equipment are primary requirements of safety. Every operator should keep his work area neat and orderly.

66. Safety devices should remain intact at all times. Tag and lock out all electrical equipment prior to any work on the filter. Keep protective covers installed around pulleys, shafts and couplings.

67. In summary, then, the vacuum filter uses a vacuum to draw sludge against a medium forming a cake. As the medium rotates out of the vat, the vacuum dries the sludge cake. The dried cake is discharged onto a conveyor which carries it away for final disposal.

68. Recall that operators of vacuum filters must give regular attention to these six factors to fulfill operational goals.

69. These goals are the production of high yield, dry cake and a quality filtrate at reasonable cost.

VACUUM FILTRATION - WORKSHEET

1. For best operational results, feed sludge should be:

 ______ a. less than 1%.

 __x__ b. 3% or more.

 ______ c. 15% or more.

 ______ d. None of the above.

2. What is the liquid called that is extracted from sludge during vacuum filtration?

 ______ a. washings

 ______ b. tailings

 ______ c. backwash

 ______ d. blowdown

 __x__ e. filtrate

3. What is an expected solids capture percent for vacuum filters?

 ______ a. 30%

 ______ b. 50%

 ______ c. 70%

 __x__ d. 85%

 ______ e. 95%

4. The different types of vacuum filters can be classified by the type of material used as the filtering medium. The <u>two</u> basic types are:

 ______ a. oscillating.

 ______ b. basket.

 __x__ c. moveable belt.

 __x__ d. Drum-scraper.

 ______ e. None of the above.

5. Matching: Choose the best answer from column B which most closely describes an item from column A. An answer may be used only once.

| Column A | | Column B |
|---|---|---|
| E | form cycle | A. Prevents stratification |
| L | drying cycle | B. Reservoir of sludge |
| G | cake release | C. Piping system inside drum |
| F | wash cycle | D. Belt creeps sideways |
| H | filter drum | E. Submergence |
| B | vat | F. Prepares media for form cycle |
| A | agitators | G. Doctor or scraper blade |
| C | manifold vacuum | H. Radial sections |
| I | media | I. Nylon, wire, cloth |
| D | biasing | J. Loading |
| K | blinding | K. Plugging of pores |
| J | lbs/hr/sq.ft. | L. Water loss and compression |
| | | M. No correct answer |

6. Vacuum filtration, as a sludge filtration - dewatering process, uses what type of pressure as the driving force to accomplish filtration?

_____ a. High head, water pressure.
_____ b. Water hammer.
_____ c. Hydraulic.
__x__ d. Atmospheric pressure.
_____ e. All of the above.

7. Which four components make up the vacuum system of the filter?

_____ a. Vat
__x__ b. Vacuum pump
__x__ c. Filtrate receiver
_____ d. Demooning bar
_____ e. Wash cycle
__x__ f. Filter drum manifold piping
_____ g. Agitators
_____ h. Reator
__x__ i. Vacuum control valve
_____ j. Discharge roller

8. What keeps the media on the drum?

__x__ a. Edge track guide.
_____ b. Demooning bar.
_____ c. Take-up roller.
_____ d. Discharge roller.
_____ e. Guardian angel.

9. As drum speed increases,

_____ a. form time increases.
_____ b. drying time increases.
_____ c. form time stays the same.
__x__ d. drying time decreases.
_____ e. None of the above.

10. What filter component separates water, solids and air?

_____ a. clarifier
_____ b. deaerator.
_____ c. reactor
__x__ d. receiver
_____ e. None of the above.

11. With regard to vacuum fitter operation, what is mooning?

_____ a. Filter operation on graveyard.
__x__ b. Media bowing because of the cake weight.
_____ c. Media creeping to one side of the roller.
_____ d. A defiant act performed during power outages.
_____ e. None of the above.

12. The vacuum control valve controls the changing levels of vacuum in which three zones?

__x__ a. Washing
__x__ b. Drying
_____ c. Demooning
_____ d. Radial
_____ e. Forming
__x__ f. Discharge
_____ g. Activated

13. Straight (only) secondary sludges are not easily dewatered by vacuum filtration. These sludges require what type(s) of treatment prior to vacuum filtration?

_____ a. Elutration.

__x__ b. Blending with primary sludge.

_____ c. High pressure pumping.

_____ d. Gravity thickening.

__x__ e. Heat treatment.

14. As the filter drum submerges or vat deep increases, more belt surface comes in contact with the sludge. Shallow submergence produces:

__x__ a. low cake yield.

_____ b. medium cake yield.

_____ c. wetter cake yield.

_____ d. high cake yield.

_____ e. no cake yield.

15. Vacuum filter production or yield is expressed as:

_____ a. g/min/l

_____ b. $lbs/sec/ft^2$

__x__ c. $lbs/hr/ft^2$

_____ d. $kg/yr/yd^2$

_____ e. None of the above.

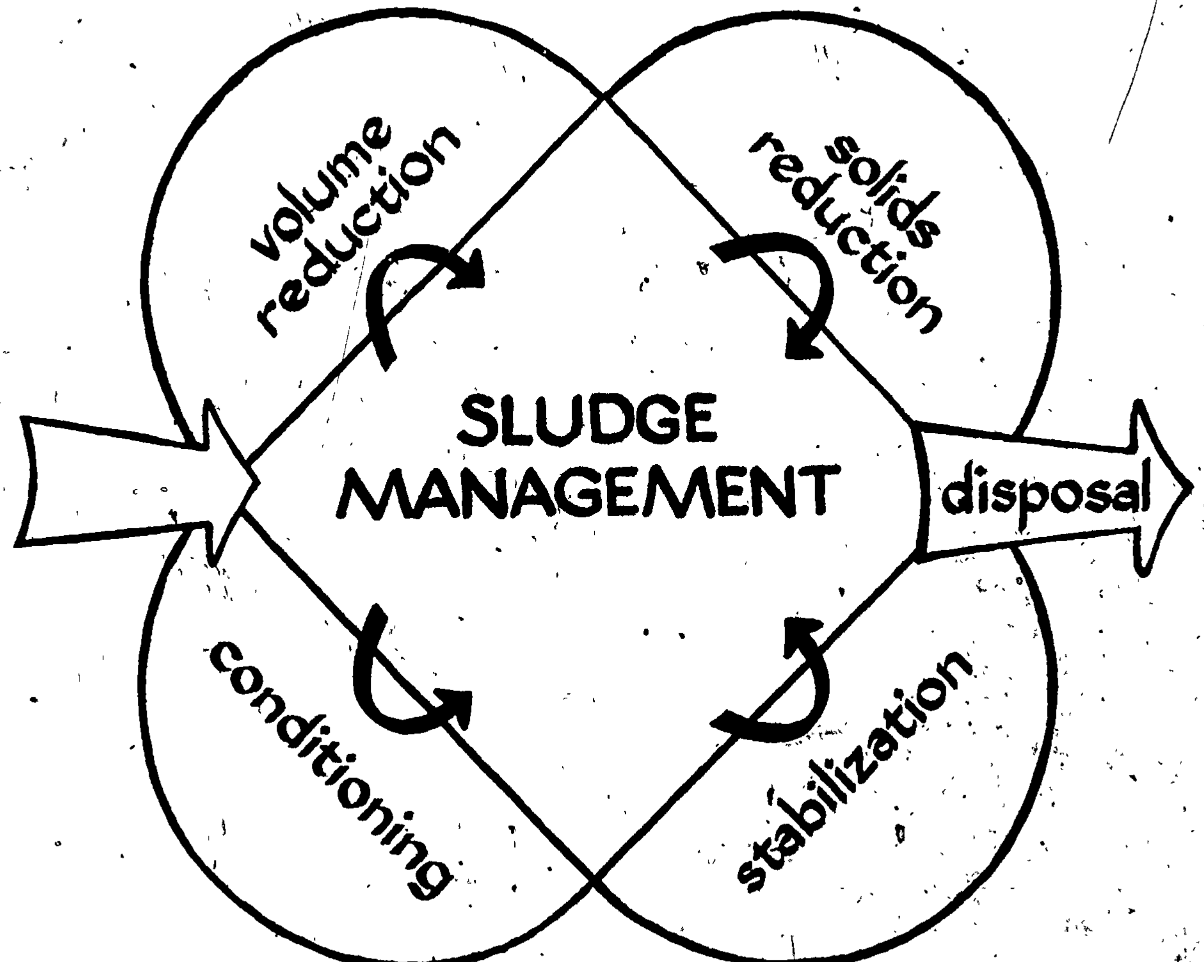
# SLUDGE TREATMENT

and

# DISPOSAL

## COURSE # 166

## VACUUM FILTRATION




## STUDENT WORKBOOK

Prepared by
Linn-Benton Community College
and
Envirotech Operating Services

SE041598

VACUUM FILTRATION

CONTENTS

# VACUUM FILTRATION

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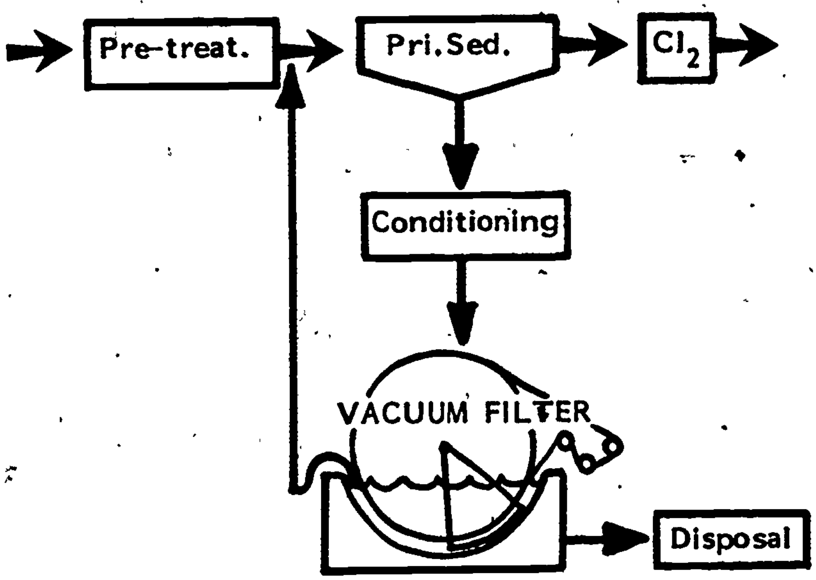
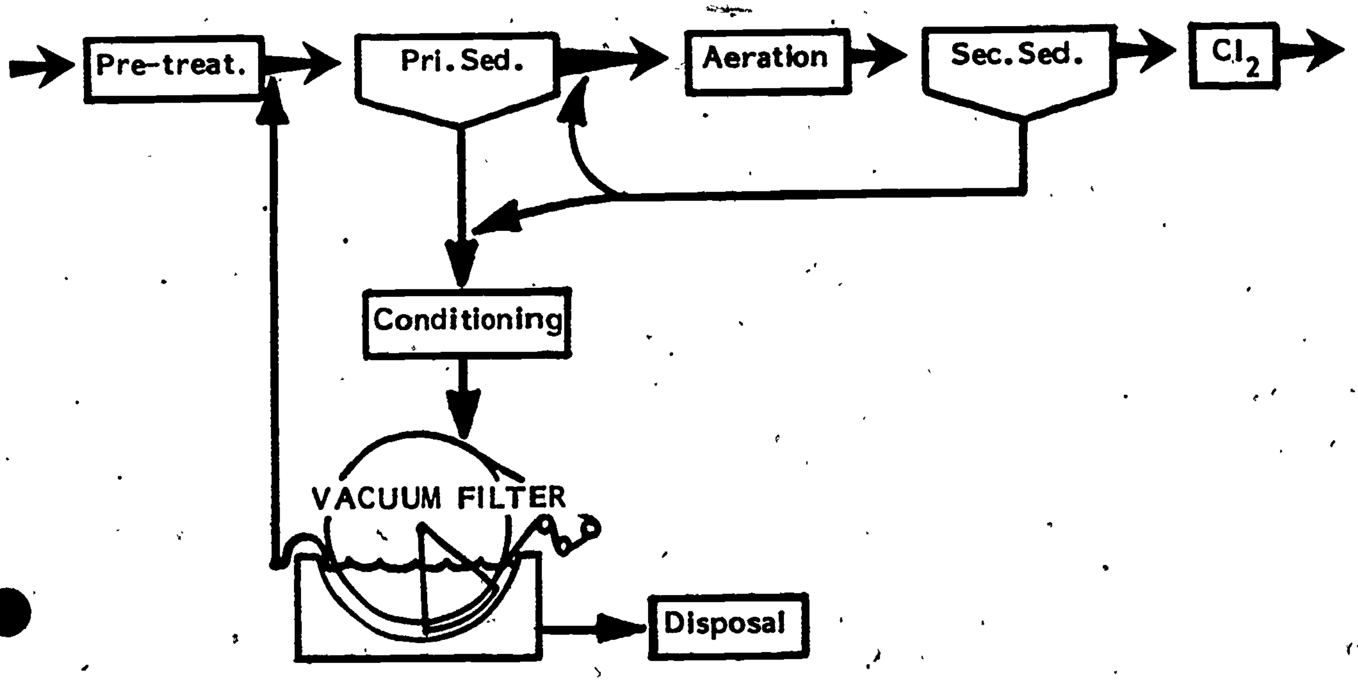
# PLANT FLOW DIAGRAMS

PRIMARY PLANT




SECONDARY PLANT



Objectives

Upon completion of this lesson you should be able to do the following:

1. Define filtration.
2. Describe how atmospheric pressure is used as the driving force to accomplish filtration.
3. Recall that the purpose of vacuum filtration is to remove water from the sludge so that the sludge volume and operating costs are reduced.
4. Recall the two different types of vacuum filters: 1) Drum-scraper, 2) Moveable belt.
5. Recall that the filter medium or cloth can be made from a variety of materials.
6. Recongnize the four operating zones and recall what occurs in each of them: A) forming, B) drying, C) discharge, D) washing.
7. Recall the function of the filter drum.
8. Recall that the filter vat holds a reservoir of sludge.
9. Recall that the vat agitator helps to keep the sludge suspended in the vat and prevents stratification.
10. Recall that the demooning bar supports the media from the drum to the discharge roller.
11. The edge track guide guides the cloth from the drum to the discharge roller.
12. Recall that the discharge roller is where the cake falls from the media to the conveyor.
13. Recall that the wash sprays are to keep the cloth clean.
14. Recall that the vacuum filter control valve controls the vacuum to the forming zone and drying zone.
15. Recall the filtrate receiver separates the water, solids and air.
16. Recall that the vacuum pump is the heart of the vacuum filter.
17. List some of the other equipment sometimes supplied to improve operation.
18. Describe how vacuum filter operations can be influenced by: A) Sludge type, B) sludge conditioning, C) applied vacuum, D) drum speed, E) drum submergence, F) media type.
19. Recall that for best operational results, feed sludges should have 3% or more solids concentration.
20. Recall that the vacuum filter yield is expressed in pounds per hour per square foot of media (lbs/hr/$ft^2$).

21. Recognise the term "blinding" as used to describe clogged media.

22. Recall that biasing is a media condition where one side is ahead of the other.

23. Mooning is a media condition where bowing occurs and this is due to cake weight.

## VACUUM FILTRATION

## GLOSSARY

Bound water - A very thin layer of water that is chemically bound to each individual particle and is not removed by mechanical dewatering methods.

Capillary water - Water that adheres between adjacent particles and can only be removed when the particles are forced out of shape and compacted.

Doctor blade - A scraper which aids in the removal of sludge cake from a media surface.

Elutriation - A process of sludge conditioning whereby the sludge is washed, either with fresh water or plant effluent, to reduce the sludge alkalinity and fine particles, thus decreasing the amount of required coagulant in further treatment steps, or in sludge dewatering.

Filter blinding - Clogging of filter media by sludge particles, coagulants, or other materials.

Filtrate - The effluent or liquid portion of a sludge removed by or discharge from a filter.

Floc shear - The breaking up or tearing of agglomerated (flocculated) solids by a mechanical (physical) force, such as excessive agitation or rapid mixing.

Floc water - Water that is trapped within floc and travels with it. This water may be removed when floc particles are compressed by mechanical means.

Free water - Water associated with sludge but not attached in any way. It is removed by simple gravitational settling.

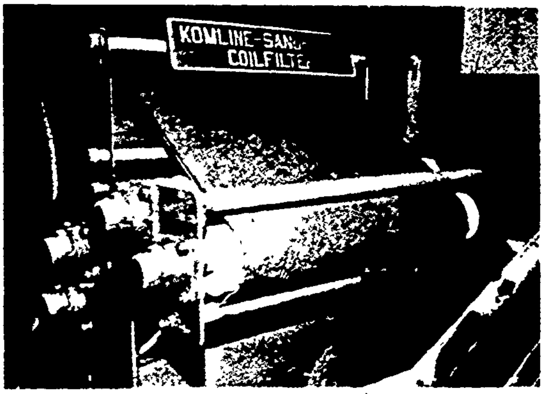
Intracellular water - Contained inside biological cells and can only be removed by disrupting the cell. This water is typically removed by heat conditioning.

Moisture content - Also called water content. Weight of water in the sludge per unit total weight of sludge, expressed as percent.

Sludge cake - The concentrated and partially dried solids produced during a dewatering process.

Vacuum filter - A filter consisting of a cylindrical drum mounted on a horizontal axis, covered with filter media, and revolving with a partial submergence in a slurry of solids and liquid. A vacuum is maintained under the filter media for the larger part of a revolution to extract moisture, yielding a partially dewatered sludge cake.

VACUUM FILTRATION-The Basics
*Remove Water
*Reduce Volume




## Vacuum Filtration - The Basics

Vacuum Filtration is a mechanical process utilizing vacuum to draw sludge from a vat up against a straining media, forming a cake. When the cake is exposed to the air, the vacuum pulls the moisture from the sludge. The cake is discharged onto a conveyor and is transported to the next disposal system. The liquid portion, filtrate, is returned to the wet end of the wastewater plant for treatment. The filtrate is a sidestream containing BOD and suspended solids and must be considered as an additional load on the plant.

The purpose of vacuum filtration is to remove water from the sludge so that the sludge volume and the operating costs are reduced for the subsequent solids handling process.

HISTORY
*1872 patented in England
*1920's used in U.S.
*1920's - 1960's, drum & scraper type were predominant
*Present - belt type filter widely used

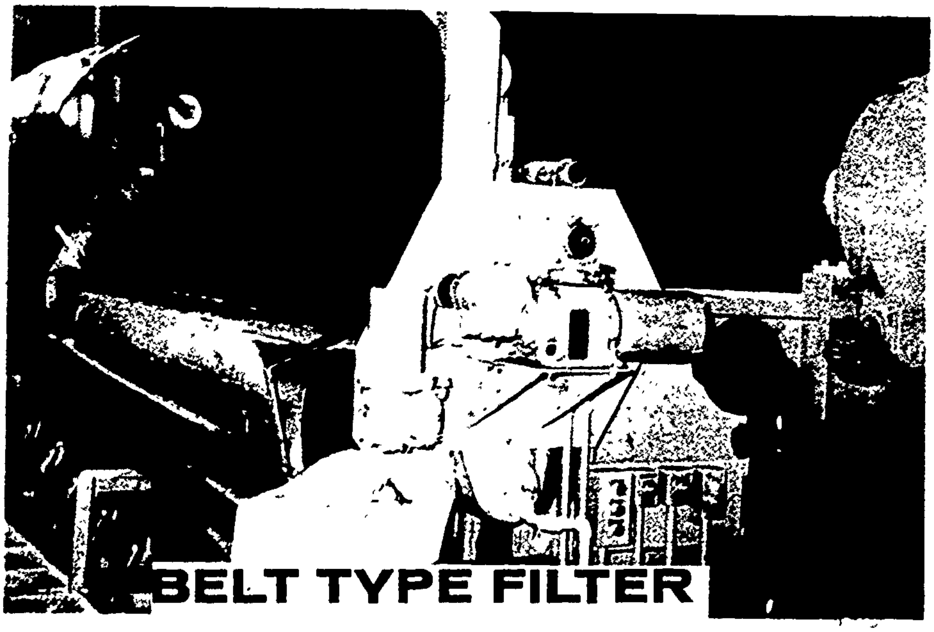
## History

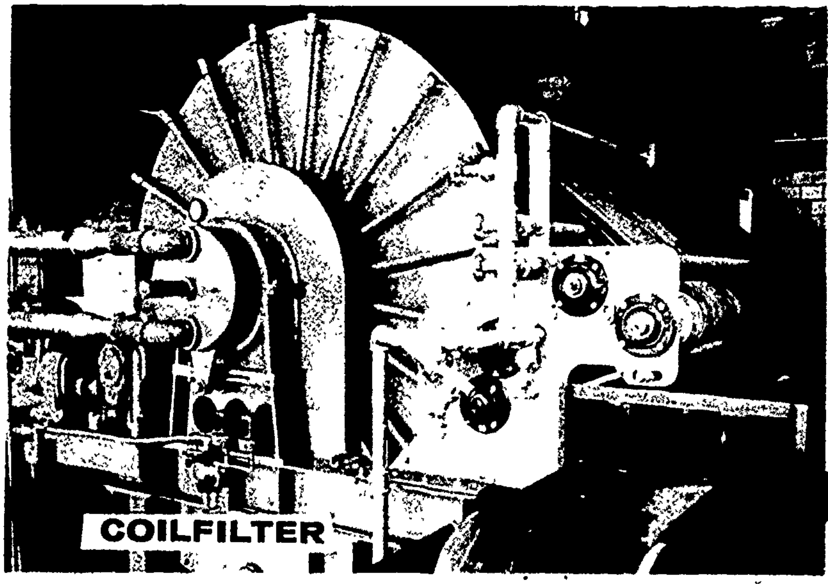
Vacuum Filters were first patented in England in 1872 by William and James Hart. The first United States application of a vacuum filter in dewatering municipal wastewater treatment plant sludge was in the mid-1920's. Until the 1960's, drum, or scraper-type rotary vacuum filters were predominant. Since then, the belt-type filter with media made from natural or synthetic fiber cloth, woven stainless steel mesh, or coil springs has predominated.

3 TYPES OF FILTERS
*Drum
*Coil
*Belt

Background Information

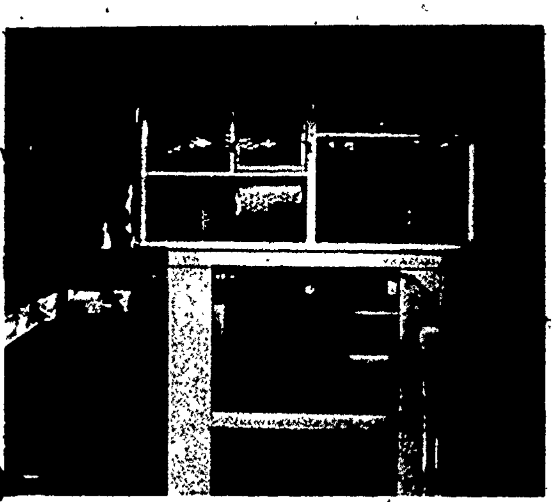
There are three principal types of rotary vacuum filters. They are the drum, coil and belt types. All three are basically the same except for the mechanism for cake discharge and the type of filter covering or media. Feed sludge to a vacuum filter should range from 3 - 10%. To achieve this, conditioning is usually required.


BELT TYPE FILTER


COILFILTER

Feed Sludge
*4 - 10%
*Typically it is conditioned

CONDITIONING
*Heat Treatment
*Chemicals
*Elutriation


*Rotating sludge conditioning tank*

## Sludge Conditioning

Before sludge is vacuum filtered, it is usually conditioned. This process prepares the sludge so that it more readily releases its water when subjected to a vacuum.

There are three methods of sludge conditioning prior to vacuum filtration:

(1) Heat treatment
(2) Chemical conditioning
(3) Elutriation

Heat treatment is a process which uses high temperature and pressure to physically change the characteristics of the sludge Sludge particles contain a large amount of bound and intracellular water. During the heat treatment process, this water is released and the sludge becomes more fibrous and readily dewaters when spread on the media of the filter. This is why the vacuum filter is sometimes referred to as an "extractor". Water is actually extracted from the conditioned sludge.

There are three principle chemicals used in sludge conditioning:

(1) Lime
(2) Ferric chloride
(3) Polymers

All have the same effect in that they act as coagulants to produce a good dewatering floc. This occurs when the surface characteristics of the sludge are changed and the particles stick closer together. In the process, floc water and capillary water are released as dewaterability improves.

Elutriation is a process of sludge condition-ing whereby the sludge is washed, either with fresh water or plant effluent. This reduces the sludge alkalinity and fine particles, thus decreasing the amount of required coagulant.

The process of sludge conditioning improves the following areas of filter performance:

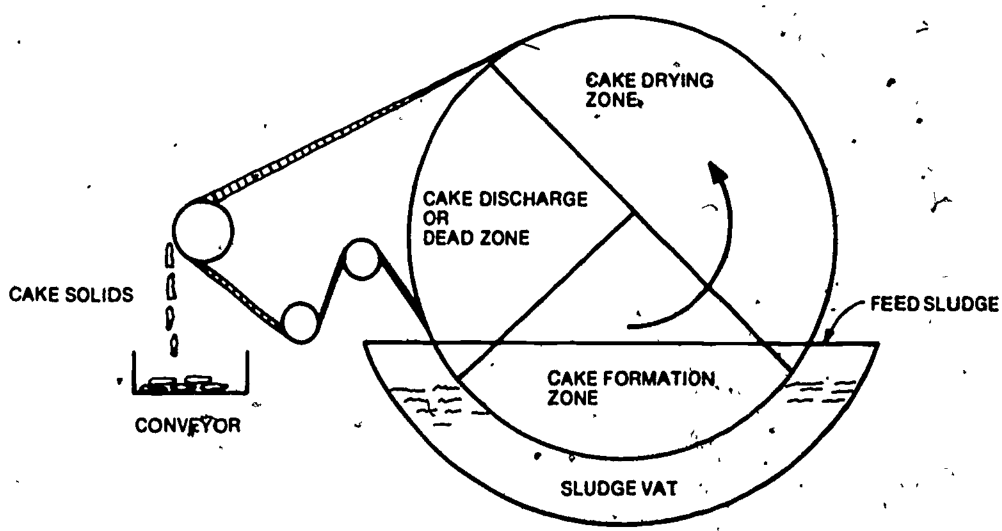
(1) Production rates
(2) Solids capture
(3) Cake solids content

Once conditioned, the sludge is moved to the filter by a feed pump, and the process of vacuum filtration begins.

4 Operating Zones
*Forming
*Drying
*Discharge
*Wash

General Vacuum Filter Operations

There are four (4) separate operating zones in the process of vacuum filtration. These are the forming, drying, discharge and wash zones. Each drum cycle contains all four operating zones.




**zones of rotary vacuum filter**

FORMING

The first zone is the cake forming zone. The forming zone starts in the vat underneath the sludge layer. Vacuum is applied to the surface of the drum within the sludge layer and the sludge is drawn up against the media and forms a cake. As the drum turns, the cake eventually leaves the vat and begins to enter the air. The moment it leaves the sludge level of the vat, it enters the drying zone.

DRYING

The drying zone is the area where moisture is pulled out of the cake. Also, air is pulled through the cake to help dry the sludge. The drying zone continues around the top of the drum. The vacuum is shut off just prior to the cloth leaving the drum. An automatic valve controls the vacuum sequence while the drum continuously rotates.

DISCHARGE

The cake then enters the cake discharge zone. The cake falls off the cloth at the discharge roller and onto a conveyor which carries it to the next disposal process.

WASH

The final zone is the media wash zone. Once the cake is off the media, it has to be cleaned before the next cycle. A series of water sprays, using plant effluent water, cleans the media.

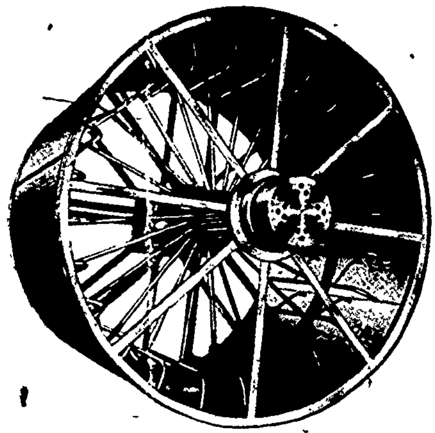
* FILTER COMPONENTS

*DRUM

FILTER COMPONENTS

Vacuum Filter Drum

The filter drum is the main component of the vacuum filter. It can be thought of as a tin can rotating through a trough (vat) of sludge.



Drum assembly illustrating arrangement of grid sections and leading and lagging (optional) drain lines.

Approximately 10 - 35% of the drum can be submerged in the sludge slurry. The drum itself is divided into radial sections. Each section is individually piped to the end of the drum where the vacuum control filter valve is located.

SECTION DIVIDERS
*Divides drum face
*Supports filter media

Section Dividers and Polypropylene Grids

The drum face consists of steel plate to which section divider strips have been welded. These section dividers are designed to maintain the section vacuum and to hold the polypropylene grids in place at each drum section. The filter cloth rides on these polypropylene grids. The grids allow vacuum to be applied evenly across the drum surface.

FILTER VAT
*Sludge reservoir
*10-35% submergence

Vacuum Filter Vat

The vacuum filter vat is a container which holds the sludge so that it can be drawn up onto the filter cloth. The vat sides are high enough to allow approximately 10 - 35% of the filter drum to submerge in the sludge level.

VAT AGITATOR
*prevent stratification
*mix vat, avoid shear

Vat Agitator

The vat agitator is a series of square bars across the width of the vat. The purpose of the vat agitator is to maintain an even sludge concentration throughout the vat by moving back and forth. The square bars reduce the potential for sludge accumulation in one area of the vat. The vat agitator speed is adjustable so that the solids stay suspended in the vat. Too high of a speed may break up the sludge floc. Speed must be fast enough to prevent stratification but slow enough to avoid floc shear.

Drum Vacuum Manifold System

The drum vacuum manifold system is a piping system located inside the filter drum, connecting each surface section to a vacuum control valve at the side of the filter. The vacuum control valve regulates the vacuum to the forming and drying zones of the filter.

Vacuum Filter Control Valve

The vacuum filter control valve, located on the side of the vacuum filter, controls the vacuum for the forming and drying zones.

DEMOONING BAR
*between drum & discharge
*supports belt & cake weight

Demooning Bar

The demooning bar is a curved bar located between the filter drum and the discharge roller. While the vacuum filter is in operation, the weight of the cake between the drum and the discharge roller can range from 100 - 500 lbs. The purpose of the demooning bar is to support the media and to reverse any effect on the cloth alignment because of the cake weight.

EDGE TRACK GUIDE
*Guide media
*Drum to discharge roller

## Edge Track Guide

Rollers are attached to the rubber edge track of the media and guide the media edge track from the filter drum to the discharge roller.

FLAPPER BAR
*underside of filter cloth
*helps discharge of cake

## Flapper Bar

The flapper bar, when installed, is used to assist in the full discharge of the cake from the filter cloth. It is simply a pipe with a series of rubber beaters bolted onto it, and is rotated by an electric motor. The rubber beaters hit the underside of the cloth and knock the cake off.

DISCHARGE ROLLER
*Removes cake

## Discharge Roller

The discharge roller is a small diameter roller and is the final turning point where the cake falls off the cloth onto the conveyor. Because of the thickness of the cake, the small diameter of the discharge roller makes it difficult for the cake to make the turn and the sludge falls off.

DOCTOR BLADE (SCRAPER)
*Removes clinging cake

## Doctor Blade or Scraper

If the sludge fails to discharge from the cloth at the discharge roller, a plastic scraper can be used. The purpose of the scraper is to insure that any cake still on the cloth is removed. For normal operation, the scraper should act only as a cake deflector. It should be positioned to effect optimum cake discharge. Care must be taken when positioning the scraper to insure that the blade does not catch on the belt joint as

**WASH SPRAYS**

*Cleans media
*Prevents blinding

it passes under the scraper. The belt may be torn if the blade touches it.

Wash Sprays

The key to the success of a vacuum filter is the fact that the filter media can be washed clean and returned to the drum each cycle. Because of this, it is imperative that proper attention and care be given to the belt washing system.

Each vacuum filter is furnished with at least three (3) media wash pipes. One is located on each side of the filter belt. These pipes are normally run continuously. For optimum operation they should be run with as much capacity and operating pressure as possible. Much more efficient washing can be accomplished with high pressure washing than with low pressure washing. The minimum pressure that should be used is 40 psi. Normal operation pressure is 40 - 60 psi. The wash sprays should be checked periodically to insure that the nozzles are not plugged. To minimize nozzle plugging, a strainer system is used in the wash water supply system.

Wash Roller

In the middle of this washing action is the wash roller. Below the wash roller is a trough which collects the wash water to drain and returns it to the wet end of the wastewater plant. This water, along with the filtrate, must be considered as an additional load on the plant.

TAKE UP ROLLER
*Maintains belt tension and alignment

FILTER CLOTH
*Many different materials

VACUUM SYSTEM
*Drum Manifold Piping
*Vacuum Control Valve
*Filtrate Receiver
*Vacuum Pump

Take Up Roller

The take up roller is an adjustable roller. Both sides of the roller are mounted on a screw with a handle. By turning the screw, the height of the take up roller can be adjusted so that the cloth maintains proper alignment and tension on the vacuum filter drum. The take up roller keeps the cloth on the vacuum filter.

Vacuum Filter Cloth

The vacuum filter media can be made of a wide variety of materials:

| | |
|---|---|
| Cotton | Polypropylene |
| Wool | Polyurethane |
| Satin | Rayon |
| Nylon | Dacron |

The edge of the media has a rubber edge track sewn on it. The rubber edge reduces wear on the cloth from the drum and assists with the alignment of the media on the filter.

Vacuum System

The vacuum system is made up of the filter drum manifold piping, the vacuum control valve, filtrate receiver, and a vacuum pump.

Vacuum Filter Drum Vacuum Manifold Piping

The vacuum filter drum vacuum piping manifold carries the filtrate and air from the surface of the drum to the vacuum control valve. Each drum section has a separate vacuum pipe.

Vacuum Control Valve

The drum sections receive vacuum control by the vacuum control valve. The valve divides the vacuum into the forming and drying zones.

The different sections of the filter drum piping come together at one end of the drum and are covered by a pipe plate. This pipe plate has ports or holes corresponding to the number of filter section pipes and rotates with the drum.

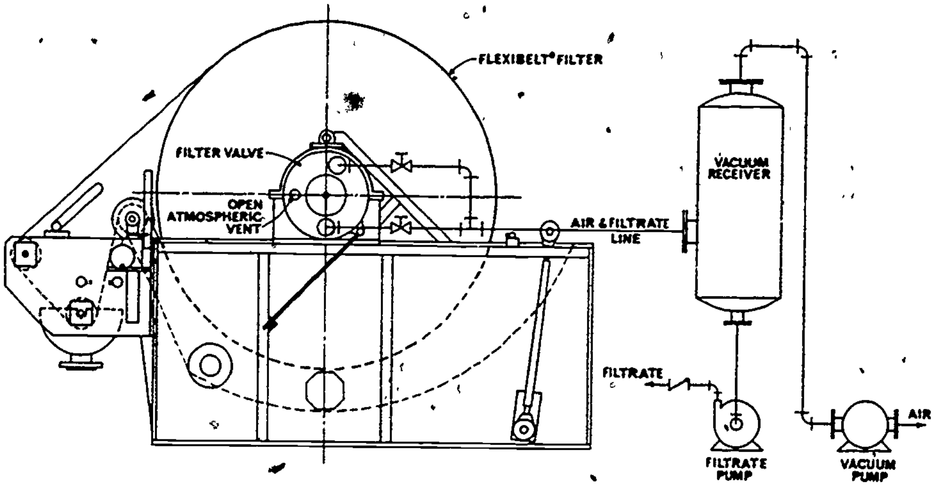
The bridge ring, which does not rotate with the filter drum, confines a higher vacuum to the cake forming zone and lower vacuum to the drying zone. The bridge ring seals off the manifold piping at the discharge zone.

From the control valve, the filtrate enters the filtrate receiver on the side of the tank. In this tank the water, solids, and air are separated.

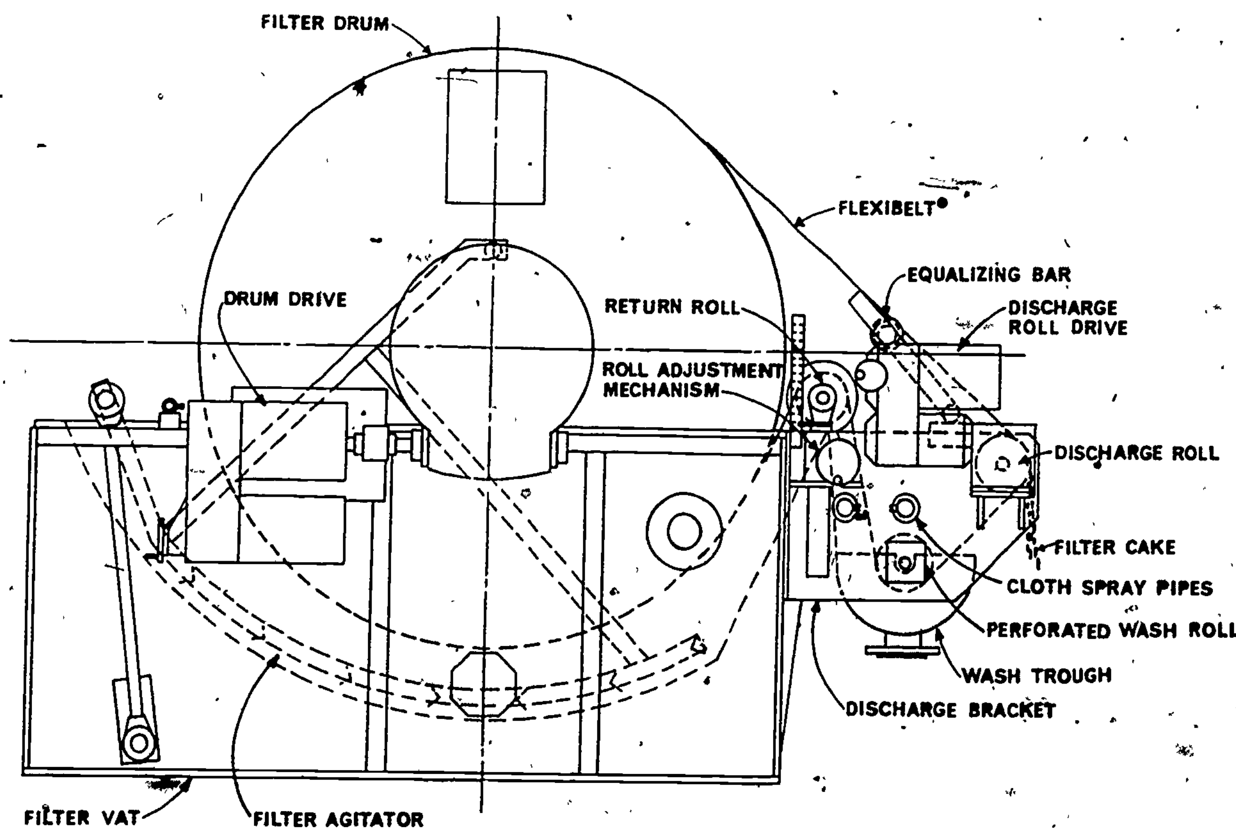
Filtrate Receiver

The filtrate contains water, solids, and air. The water and solids are separated from the air by the filtrate receiver

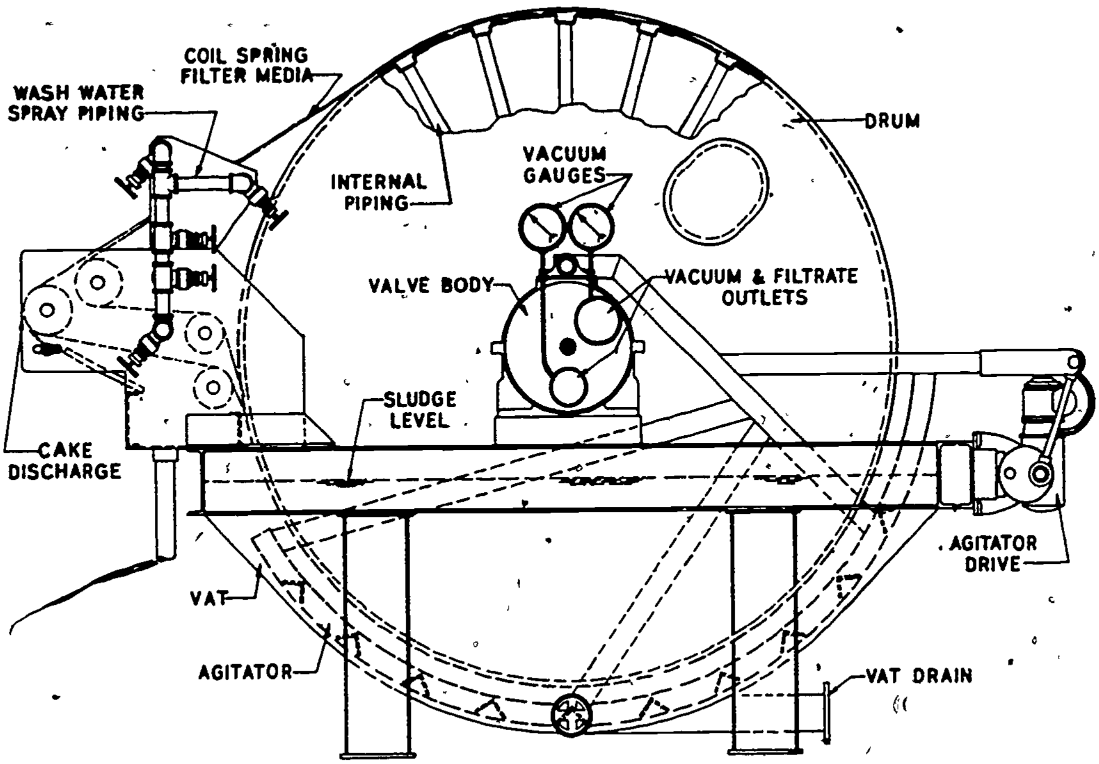
The filtrate enters the receiver on the side so that a spinning action is established. The spinning filtrate separates, with the water and solids being forced along the wall of the re-




Schematic diagram of simple FLEXIBELT vacuum filter dewatering system.




Belt-Type




*Coilfilter Elevation*

ceiver. The filtrate settles to the bottom of the tank where it is collected and pumped to the headworks or to primary treatment. The air portion passes out the top of the receiver on its way to the vacuum pump.

Vacuum Pump

The vacuum pump is the heart of the vacuum filter. The most commonly used vacuum pump is a rotary type.

Operation
*Reacts to process changes

Operation

The goal of a wastewater treatment plant is to remove solid materials from the influent stream flow. The vacuum filter is designed to dewater these solids to a point where they can be handled more easily.

Vacuum filtration is a mechanical process and, as such, reacts quickly to process changes occurring in the treatment facility. Because it is a sophisticated mechanical process, it requires attention of an experienced operator.

MEDIA ADJUSTMENT
* Mooning
* Biasing

Mooning

Mooning is indicated by an arched curve in the media fastener or clipper joint. This condition occurs when the center of the clipper either leads or trails the edges. This form of media distortion is a major cause of belt wrinkling, which, if allowed to become extreme, will result in a loss of vacuum, poor cake formation, excessive wear of the cloth and damage to the rubber edging.

The most common cause of mooning is excessive cake weight between the filter drum and the discharge roller. Adjustment of the demooning bar will correct most mooning.

Biasing

Biasing occurs when one end of the clipper seam is leading the other. This happens when the leading edge of the media is traveling a shorter distance than the other side in the discharge zone. If the bias is not corrected, the cloth will move across the drum toward the side with the leading clipper edge. Once the cloth has moved, the drum grid surface will be exposed creating excessive vacuum leaks and loss of cake. The filter media may also be damaged.

To correct a bias the take up roller should be adjusted so that the entire cloth is traveling the same distance. The take up roller keeps the cloth on the drum. Once a cloth has started to move across the filter drum, the cloth tension must be loosened so that the media can be pulled back by hand.

A properly tracking media has a straight and level clipper seam. During the start up procedure, make sure the cloth is wet and tracking on the drum without a bias or a moon. Correction of these two media problems will make filter operation easier and more productive.

VAT SLUDGE LEVEL & DRUM SPEED
*Affects forming and drying zones

Vat Sludge Level and Drum Speed

The vat sludge level can be raised or lowered. This controls the amount of the forming and drying zones during each cycle. The higher the vat level the more forming zone and the less drying zone and vice versa. The drum speed controls the amount of time the sludge cake is in the forming and drying zone. By adjusting both drum speed and vat level the operator should be able to achieve good production with dry cake and a complete cake discharge.

Blinding

Blinding occurs when the filter media becomes plugged with sludge. The net result is a loss in filter production and a need to clean the media.

Expected Results

The sludge cake percent solids will generally be 20-35% for chemically conditioned sludge and 25-45% with thermally conditioned sludge. The filtrate solids concentration will normally range from 100-600 mg/l during good filter operation. Capture across the filter is usually about 85%. This means that for every 100 pounds of solids sent to the filter, 85 are dewatered and removed and 15 are lost in the filtrate and sent back to the plant.

PRODUCTION
*pounds/hour/square foot

## Measuring Vacuum Filter Production

The yield from a vacuum filter, expressed in pounds per hour per square foot of media, is the common measure of performance. The yield is directly related to the solids content of the feed sludge, the cake formation time, and the level of vacuum applied. The yield is indirectly related to the total cycle time, the cake solids concentration, and the media and cake resistance.

OPERATING GOALS
*High yield
*Low moisture
*Low costs

High filter yield with low moisture content, low solids content in filtrate and wash water and low operating costs are the primary goals of filter operation.

PROCESS CHANGES
*Drum Speed
*Drum Submergence
*Agitation Speed
*Vacuum Level

In the application of these general principles, the operator has little control over the solids content of the feed sludge. This makes it very important to closely monitor sludge conditioning to achieve the best feed sludge possible. The drum speed can be varied which changes the cycle time. Varying the level of drum submergence (vat level) changes the amount of forming and drying zones. The agitation speed can be varied to produce changes in overall vat solids concentration. Adjusting the vacuum level by varying the compressant flow rate to the vacuum pumps is another option for controlling the process. Each of these variables has a definite effect on filter performance and affords many opportunities to optimize performance.

## Safety

Good housekeeping and an orderly arrangement of material and equipment is a primary requirement of safety. Every operator should keep

SAFETY

*Good Housekeeping
*Protective Clothing
*Safety devices intact
*Tag and Lock Out Procedure
*Proper Chemical Handling

his work area neat and orderly.

Protective clothing, such as gloves, glasses and hard hats should be worn at all times.

Safety devices should remain intact at all times. Tag and lock out all electrical equipment prior to any work on the filter. Keep protective covers installed around pulleys, shafts and couplings.

Sludge conditioning chemicals must be handled properly to prevent injury. Protective clothing, proper ventilation, and breathing apparatus must be worn when handling ferric chloride or lime. Polymer spillage must be carefully cleaned up because it is very slippery. Granulated salt may be used as a "slip-killer."

SUMMARY

*Reliability
*Efficiency
*Economy

In summary, then, the vacuum filter uses a vacuum to draw sludge against a medium forming a cake. As the medium rotates out of the vat, the vacuum dries the sludge cake. The dried cake is discharged onto a conveyor which carries it away for final disposal.

Recall that operators of vacuum filters must give regular attention to these six factors to fulfill operational goals.

These goals are the production of high yield, dry cake, and a quality filtrate at reasonable cost.

# VACUUM FILTRATION

References


1. Sludge Dewatering, Manual of Practice No. 20, WPCF, 1969.
2. Sludge Treatment and Disposal - Process Design Manual, EPA 626/1-79-011.
3. Operation of Wastewater Treatment Plants, Second Edition, Vol. III; California State University, Sacramento, 1980.

VACUUM FILTRATION - WORKSHEET

1. For best operational results, feed sludge should be:

   ______ a. less than 1%.

   ______ b. 3% or more.

   ______ c. 15% or more.

   ______ d. None of the above.

2. What is the liquid called that is extracted from sludge during vacuum filtration?

   ______ a. washings

   ______ b. tailings

   ______ c. backwash

   ______ d. blowdown

   ______ e. filtrate

3. What is an expected solids capture percent for vacuum filters?

   ______ a. 30%

   ______ b. 50%

   ______ c. 70%

   ______ d. 85%

   ______ e. 95%

4. The different types of vacuum filters can be classified by the type of material used as the filtering medium. The <u>two</u> basic types are:

   ______ a. oscillating.

   ______ b. basket.

   ______ c. moveable belt.

   ______ d. Drum-scraper.

   ______ e. None of the above.

5. Matching: Choose the best answer from column B which most closely describes an item from column A. An answer may be used only once.

| Column A | Column B |
|---|---|
| ______ form cycle | A. Prevents stratification |
| ______ drying cycle | B. Reservoir of sludge |
| ______ cake release | C. Piping system inside drum |
| ______ wash cycle | D. Belt creeps sideways |
| ______ filter drum | E. Submergence |
| ______ vat | F. Prepares media for form cycle |
| ______ agitators | G. Doctor or scraper blade |
| ______ manifold vacuum | H. Radial sections |
| ______ media | I. Nylon, wire, cloth |
| ______ biasing | J. Loading |
| ______ blinding | K. Plugging of pores |
| ______ lbs/hr/sq.ft. | L. Water loss and compression |
| | M. No correct answer |

6. Vacuum filtration, as a sludge filtration - dewatering process, uses what type of pressure as the driving force to accomplish filtration?

______ a. High head, water pressure.

______ b. Water hammer.

______ c. Hydraulic.

______ d. Atmospheric pressure.

______ e. All of the above.

7. Which four components make up the vacuum system of the filter?

______ a. Vat

______ b. Vacuum pump

______ c. Filtrate receiver

______ d. Demooning bar

______ e. Wash cycle

______ f. Filter drum manifold piping

______ g. Agitators

______ h. Reator

______ i. Vacuum control valve

______ j. Discharge roller

8. What keeps the media on the drum?

______ a. Edge track guide.
______ b. Demooning bar.
______ c. Take-up roller.
______ d. Discharge roller.
______ e. Guardian angel.

9. As drum speed increases,

______ a. form time increases.
______ b. drying time increases.
______ c. form time stays the same.
______ d. drying time decreases.
______ e. None of the above.

10. What filter component separates water, solids and air?

______ a. clarifier
______ b. deaerator
______ c. reactor
______ d. receiver
______ e. None of the above.

11. With regard to vacuum fitter operation, what is mooning?

______ a. Filter operation on graveyard.
______ b. Media bowing because of the cake weight.
______ c. Media creeping to one side of the roller.
______ d. A defiant act performed during power outages.
______ e. None of the above.

12. The vacuum control valve controls the changing levels of vacuum in which three zones?

______ a. Washing
______ b. Drying
______ c. Demooning
______ d. Radial
______ e. Forming
______ f. Discharge
______ g. Activated

13. Straight (only) secondary sludges are not easily dewatered by vacuum filtration. These sludges require what type(s) of treatment prior to vacuum filtration?

_____ a. Elutration.

_____ b. Blending with primary sludge.

_____ c. High pressure pumping.

_____ d. Gravity thickening.

_____ e. Heat treatment.

14. As the filter drum submerges or vat deep increases, more belt surface comes in contact with the sludge. Shallow submergence produces:

_____ a. low cake yield.

_____ b. medium cake yield.

_____ c. wetter cake yield.

_____ d. high cake yield.

_____ e. no cake yield.

15. Vacuum filter production or yield is expressed as:

_____ a. g/min/l

_____ b. $lbs/sec/ft^2$

_____ c. $lbs/hr/ft^2$

_____ d. $kg/yr/yd^2$

__/__ e. None of the above.